WIND ENGINEERING &
AIR QUALITY CONSULTANTS

APM Ad Hoc Subcommittee Update:
PRIME2 Research Study

2016 Regional, State, and Local Modelers' Workshop

November 15, 2016

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PRIME2 Subcommittee

Created with the purpose of:

- Establishing a mechanism to review, approve and implement new science into the model for this and future improvements
- Providing a technical review forum to improve the PRIME building downwash algorithms

EPA and Industry Funded Research in the Past

Proposed improvements to AERMOD

APM's Proposed Model

Outline
PRIME2 Research Study

1. Background
2. Phase 1 Scope, Summary, and Schedule
   – Solid Buildings
   – Porous Buildings
3. Preliminary Results

Objective

- Correct known problems in the theory
- Incorporate and advance the current state of science
- Expand the types of structures that can be accurately handled
- Properly document and verify model formulation and code for PRIME2
- Collaborate with EPA to ensure a scientifically valid justification and swift approval of new/improved model

Why a New Downwash Model?

- AERMOD's PRIME algorithm based on research carried out before 2000
- Original theory based on a limited number of building dimensions and building types
- Theory is not suitable for porous, streamlined, wide or elongated structures
- Theory based on theoretical assumptions that can be improved

Background

1. Downwash

2. BPIP

3. PRIME

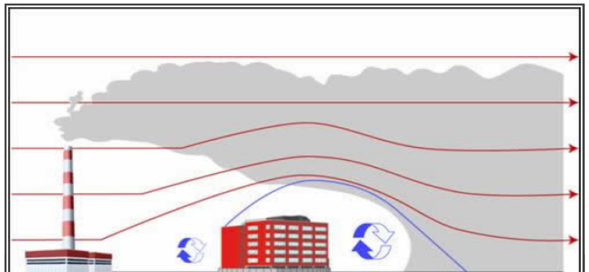


Image from Lakes Environmental Software

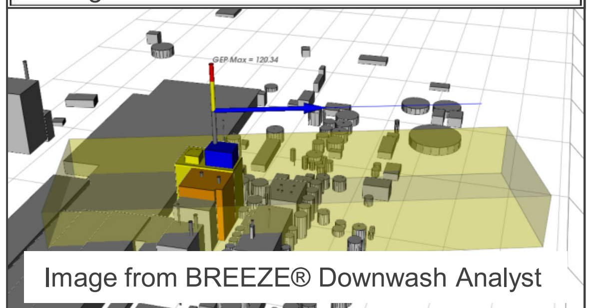
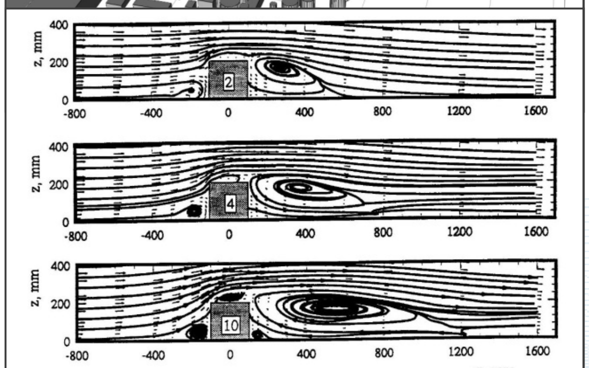


Image from BREEZE® Downwash Analyst

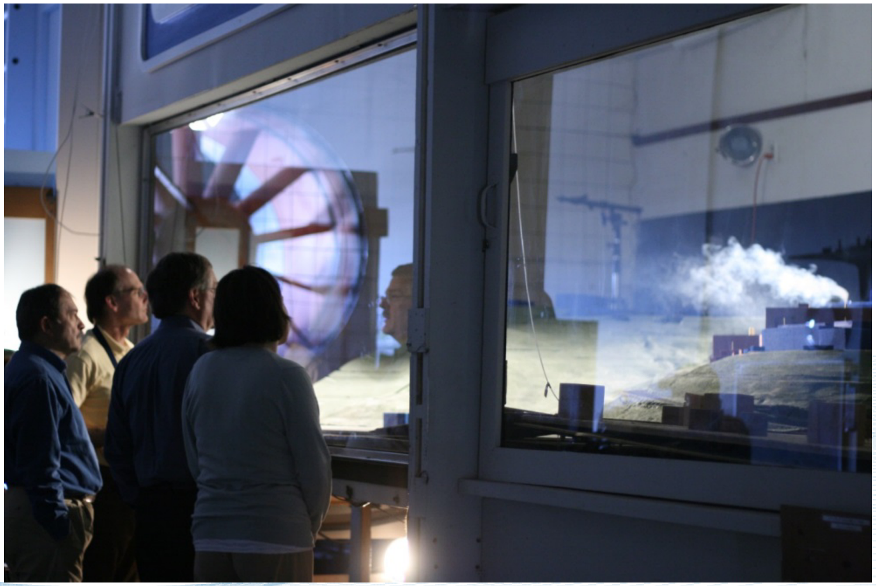


Snyder, W. H. and R. E. Lawson, 1994: Wind tunnel measurements of flow fields in the vicinity of buildings, 8th AMS Conf. on Appl. Air Poll. Meteorol., with AWMA, Nashville, TN.

Phase 1

Funding Partners

- American Forest & Paper Association
- American Petroleum Institute
- Corn Refiners Association



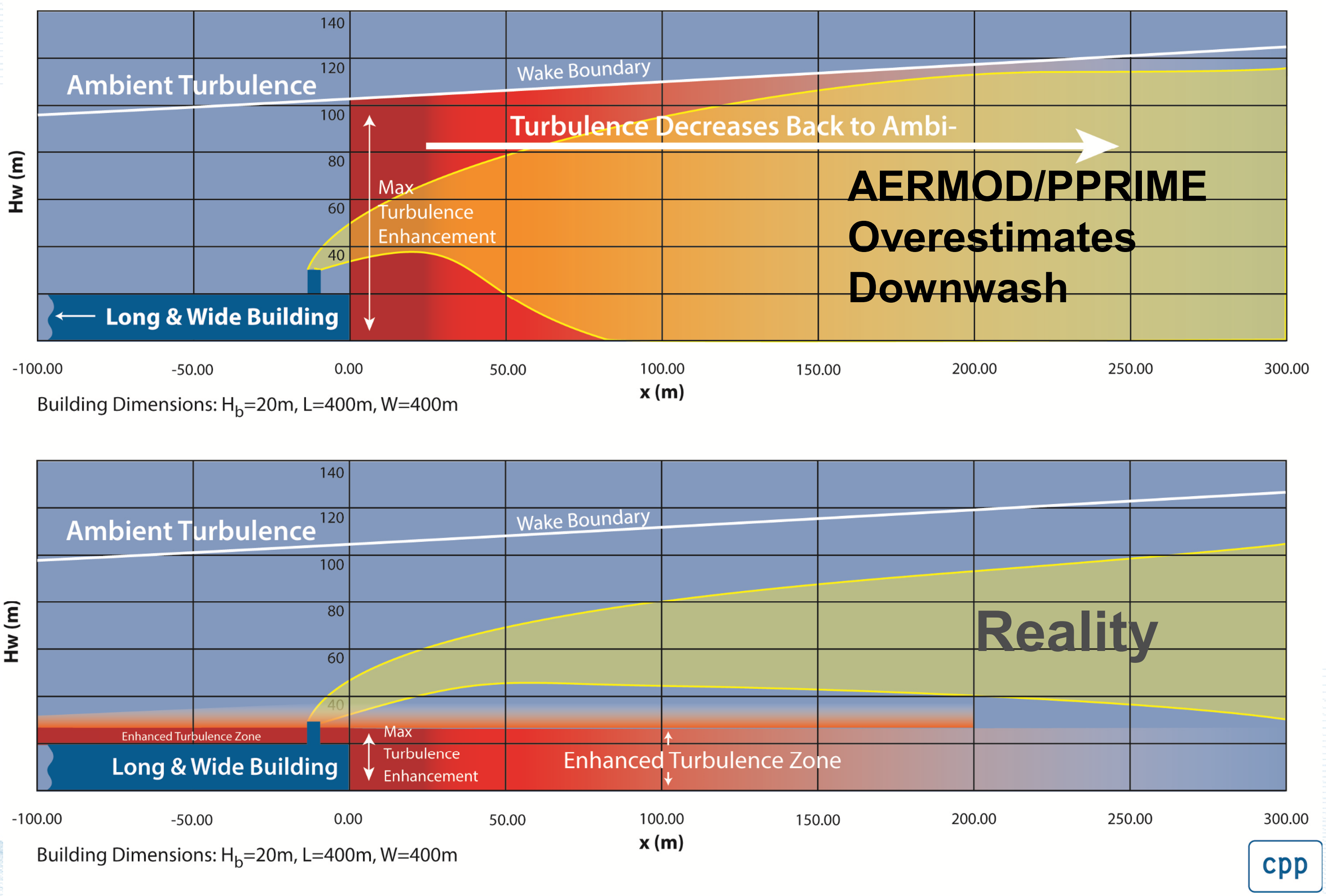
Phase 1 Scope Summary and Schedule

Task	Description	Completed by
1	Project plan finalization	9/30/2016
2	Limited wind tunnel testing	11/14/2016
3	Evaluate PRIME theory	12/15/2016
4	Update PRIME formulation	12/31/2016
5	Evaluate PRIME2 against existing wind tunnel data bases	1/15/2016
6	Limited consequence analysis	1/31/2017
7	Presentation of results	2/15/2017

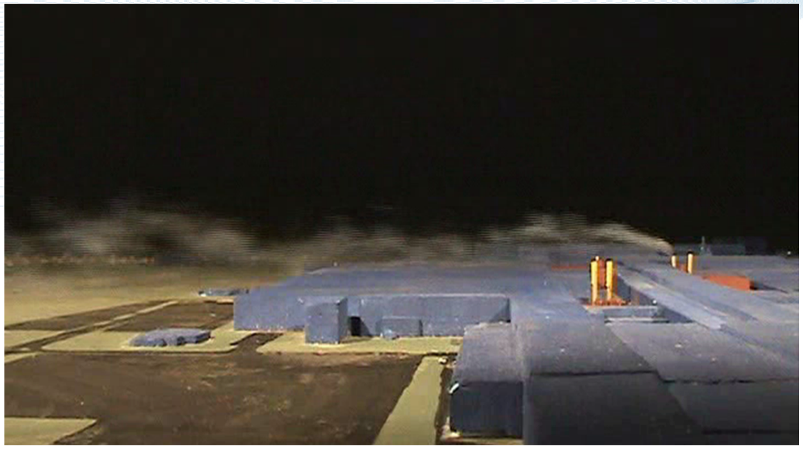
Scope

- Solid Buildings
  - velocity/turbulence decay to ambient above building roof
  - Improved velocity/turbulence decay rate versus downwind distance
- Porous Buildings
  - Make streamlines horizontal
  - Update the velocity deficit/turbulence enhancement constants

Illustration of AERMOD Building Downwash Problem: Height of Building Downwash Zone Overestimated in PRIME



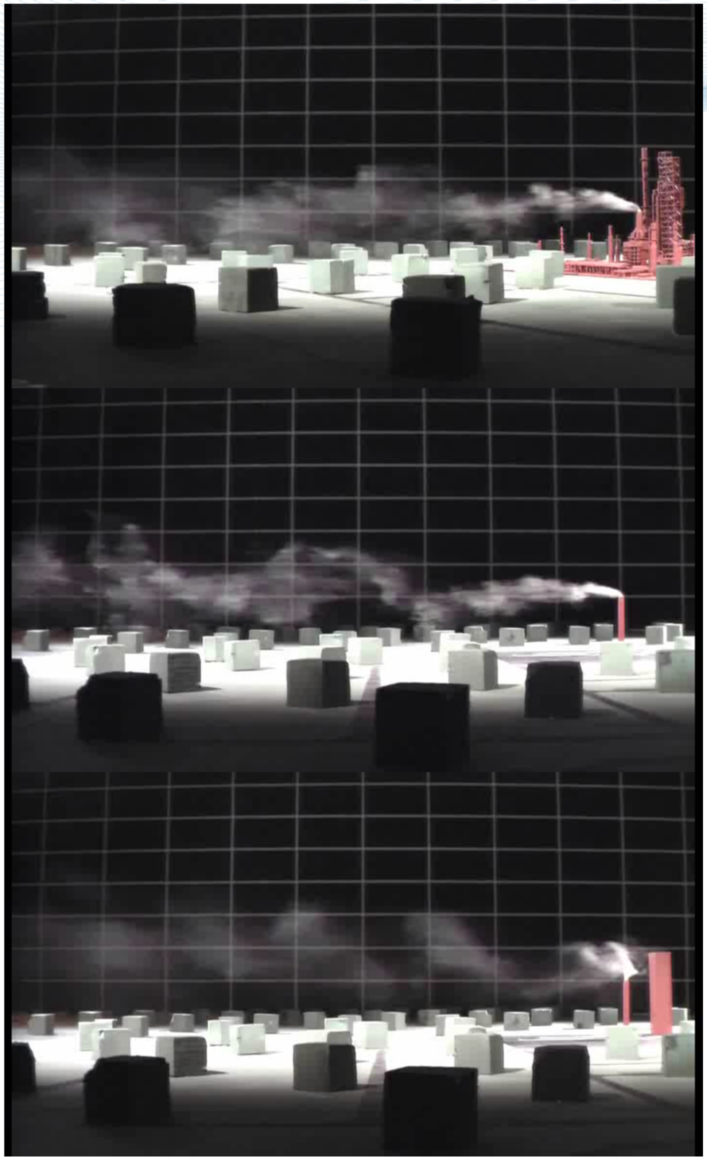
Wake Turbulence Overstated In AERMOD



Long/Wide/Short Building
Short Stack

No Buildings
Short Stack
Same roughness
No Building Dispersion Similar

Streamlines for Lattice Structures Should be Horizontal



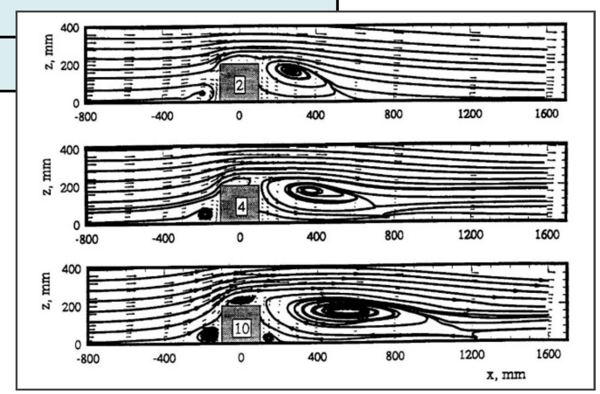
Refinery Structures Upwind
- Horizontal Flow

No Structures

Solid BPIP Structure Upwind

Solid Building: Limited Wind Tunnel Testing

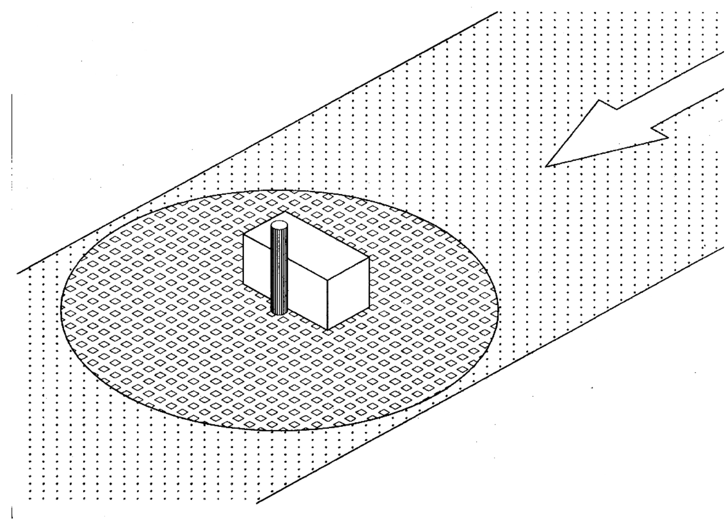
Snyder and Lawson (1994) Database			
H_b(mm)	W/H_b	L/H_b	Comment
200	1,2,4,10	1	
200	1	0.0.5,1,2,4	
200	1	1	Rotated 45 degrees
600	0.333	0.333	
400	0.5	0.5	



Phase 1 Testing			
H_b(mm)	W/H_b	L/H_b	Comment
200	4	4	
200	10	10	

Solid Building: Limited Wind Tunnel Testing

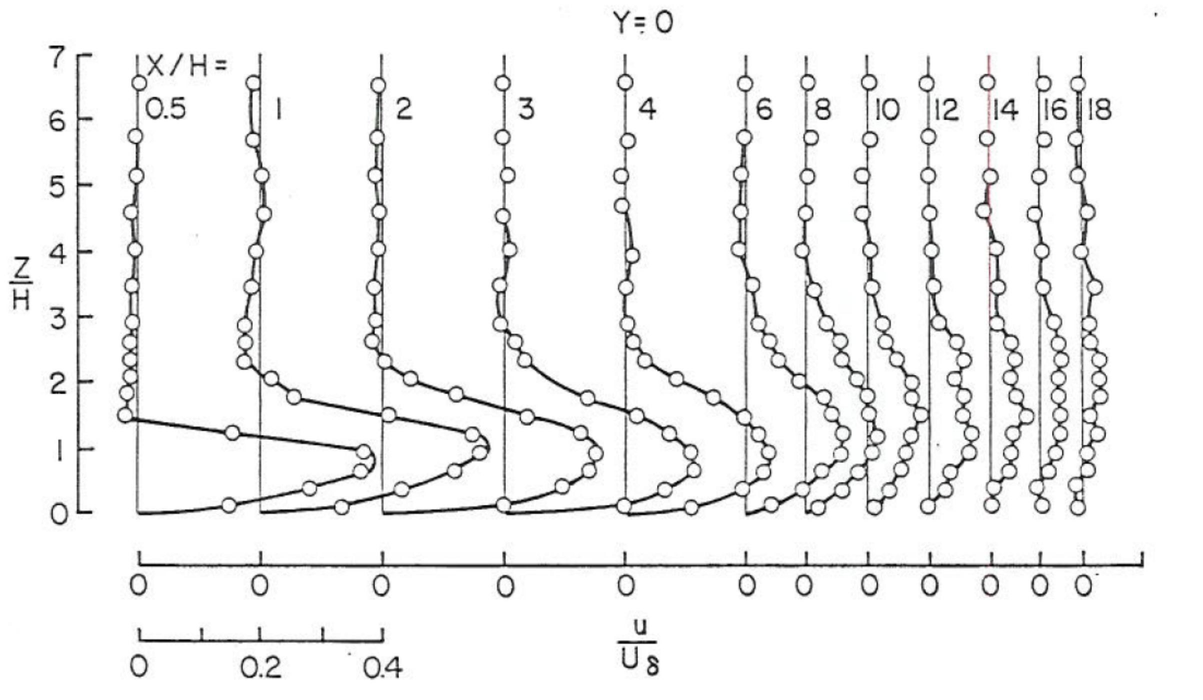
- Same boundary layer setup as Snyder and Lawson
  - $z_o = 0.2$ m
  - 1:350 model scale
    - versus 1:200 used by Snyder and Lawson
- Measurements (OmniProbe)
  - U, u', v' and w' versus height (z)
  - x- distances from downwind face: $0.5H_b$; $1H_b$; $2H_b$; $4H_b$; $8H_b$; $16H_b$.
  - y location: building centerline



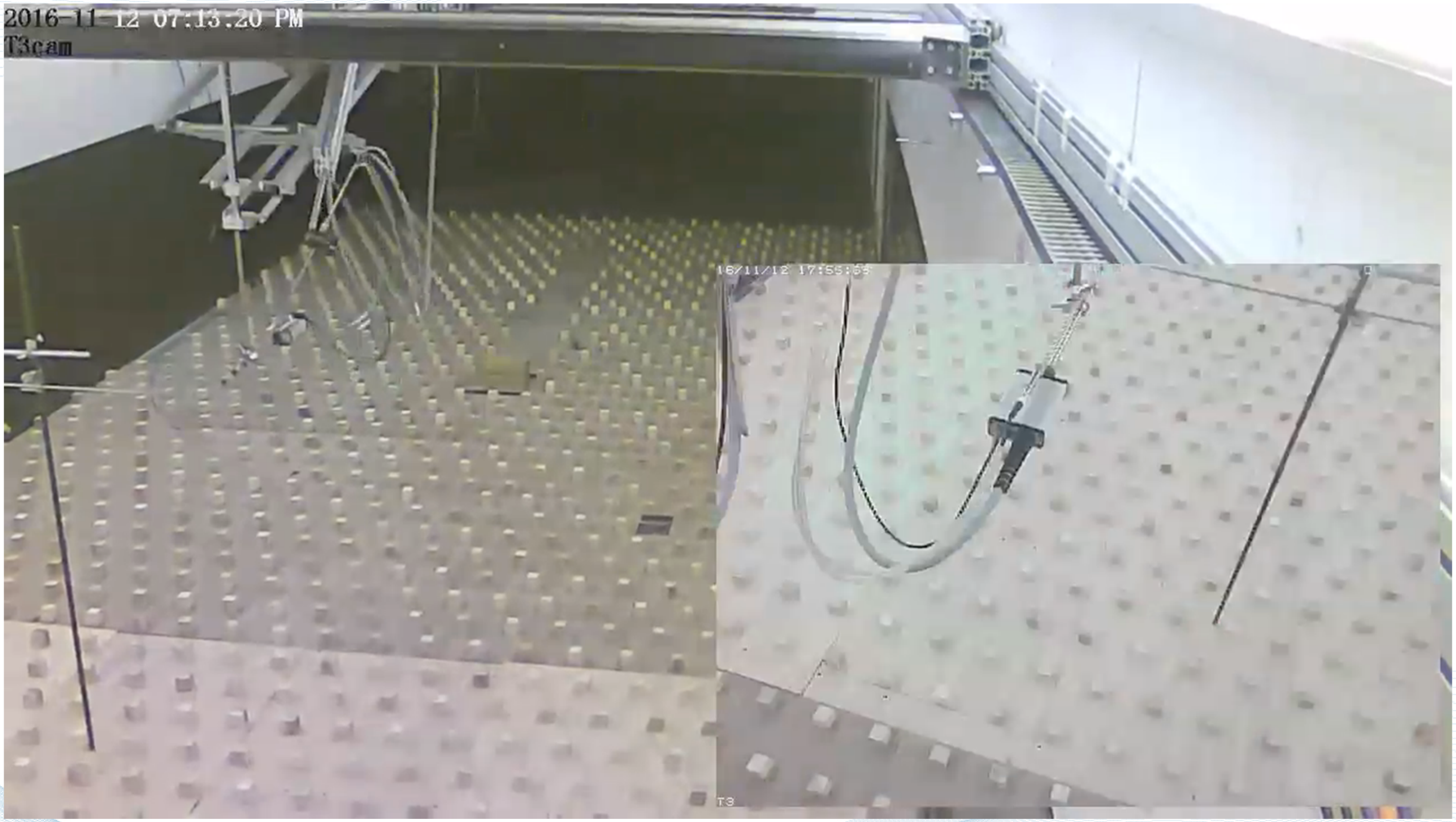
Solid Building: Limited Wind Tunnel Testing

Typical Results From Woo et al., 1977

H_b = 6.5 cm; W/H_b = 2.4; L/H_b = 0.75

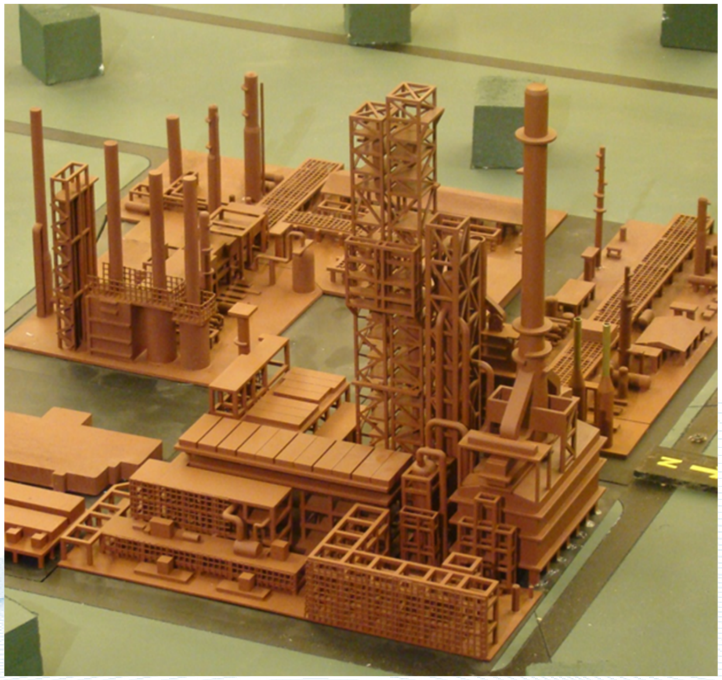


Solid Building: Limited Wind Tunnel Testing



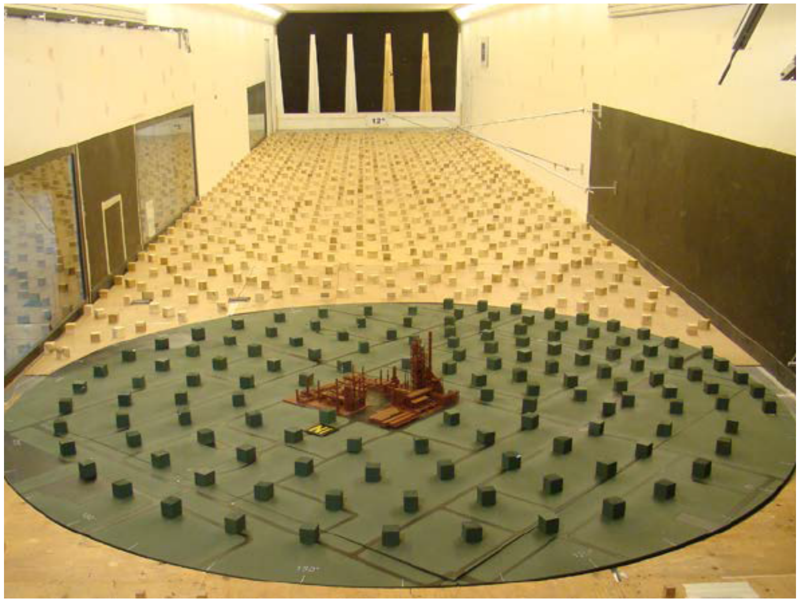
Porous Structure: Limited Wind Tunnel Testing

- Three lattice structures
  - Structure 1 from previous CPP study.
  - Structure 2: similar shape, but constructed of 50% porous screen.
  - Structure 3: 1:2:1 porous building constructed of 50% porous screen.



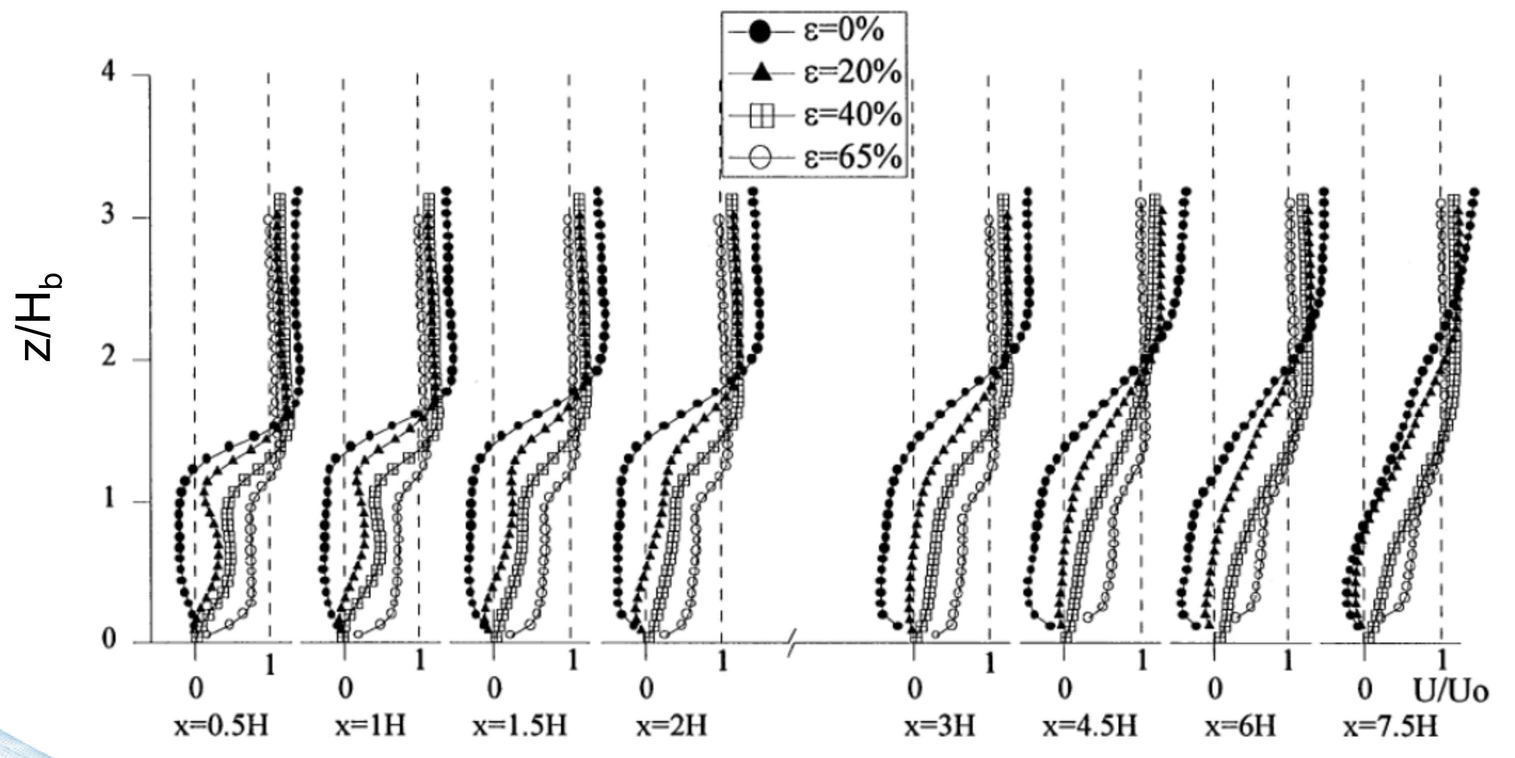
Porous Structures: Limited Wind Tunnel Testing

- Same boundary layer setup as previous testing
  - z_o = 0.2 m
  - 1:350 model scale
- Measurements
  - U, u', v' and w' versus x
  - x distances from downwind face
    - $0.5H_b$; $1H_b$; $2H_b$; $4H_b$; $8H_b$; $16H_b$;



Porous Structures: Limited Wind Tunnel Testing

Typical Results From Lee, 1999



Evaluation of PRIME Theory

- Assembled existing databases and converted to Excel format
  - Snyder and Lawson (solid buildings): in progress by EPA
  - Woo et al., 1977 and Peterka et al., 1985 (solid buildings)
  - Fang et at., 1997 (Porous fences)
  - Lee and Kim, 1999 (Porous fences)
- Will add new data collected in Task 2.
- Evaluate existing PRIME equations: turbulence enhancement, velocity deficit and streamlines
- Develop new equations: turbulence enhancement, velocity deficit and streamlines.

Evaluation of PRIME Theory
PRIME Wake Turbulence Intensity i_z Equation

Starting Point

$$i_z(\xi, y, z) = \left[\frac{RMS\ WS}{Average\ WS}\right]_{wake} = \left[\frac{Approach\ RMS\ WS + \text{RMS WS Difference}\left(\frac{\xi}{H}\right)^{-\frac{2}{3}}}{Approach\ Mean\ WS_o + \text{Mean WS Different}\left(\frac{\xi}{H}\right)^{-\frac{2}{3}}}\right]$$

Final Equation – Constant Factor Versus Height

$$i_z(\xi, y, z) = i_{zo}(z)\left[\frac{1+\frac{\Delta\sigma_{wo}}{\sigma_{wo}}\left(\frac{\xi}{R}\right)^{-\frac{2}{3}}}{1+\Delta U_o/U_o\left(\frac{\xi}{R}\right)^{-\frac{2}{3}}}\right] = i_{zo}(z)\left[\frac{1+0.7\left(\frac{\xi}{R}\right)^{-\frac{2}{3}}}{1-0.7\left(\frac{\xi}{R}\right)^{-\frac{2}{3}}}\right]$$

Evaluation of PRIME Theory
PRIME2 Wake Turbulence Intensity i_z

Same Starting Point

$$i_z(\xi, y, z) = \left[\frac{RMS\ WS}{Average\ WS}\right]_{wake} = \left[\frac{Approach\ RMS\ WS + \text{RMS WS Difference}\left(\frac{\xi}{H}\right)^{-\frac{2}{3}}}{Approach\ Mean\ WS_o + \text{Mean WS Different}\left(\frac{\xi}{H}\right)^{-\frac{2}{3}}}\right]$$

Final Equation – Varies with height, porosity, and distance

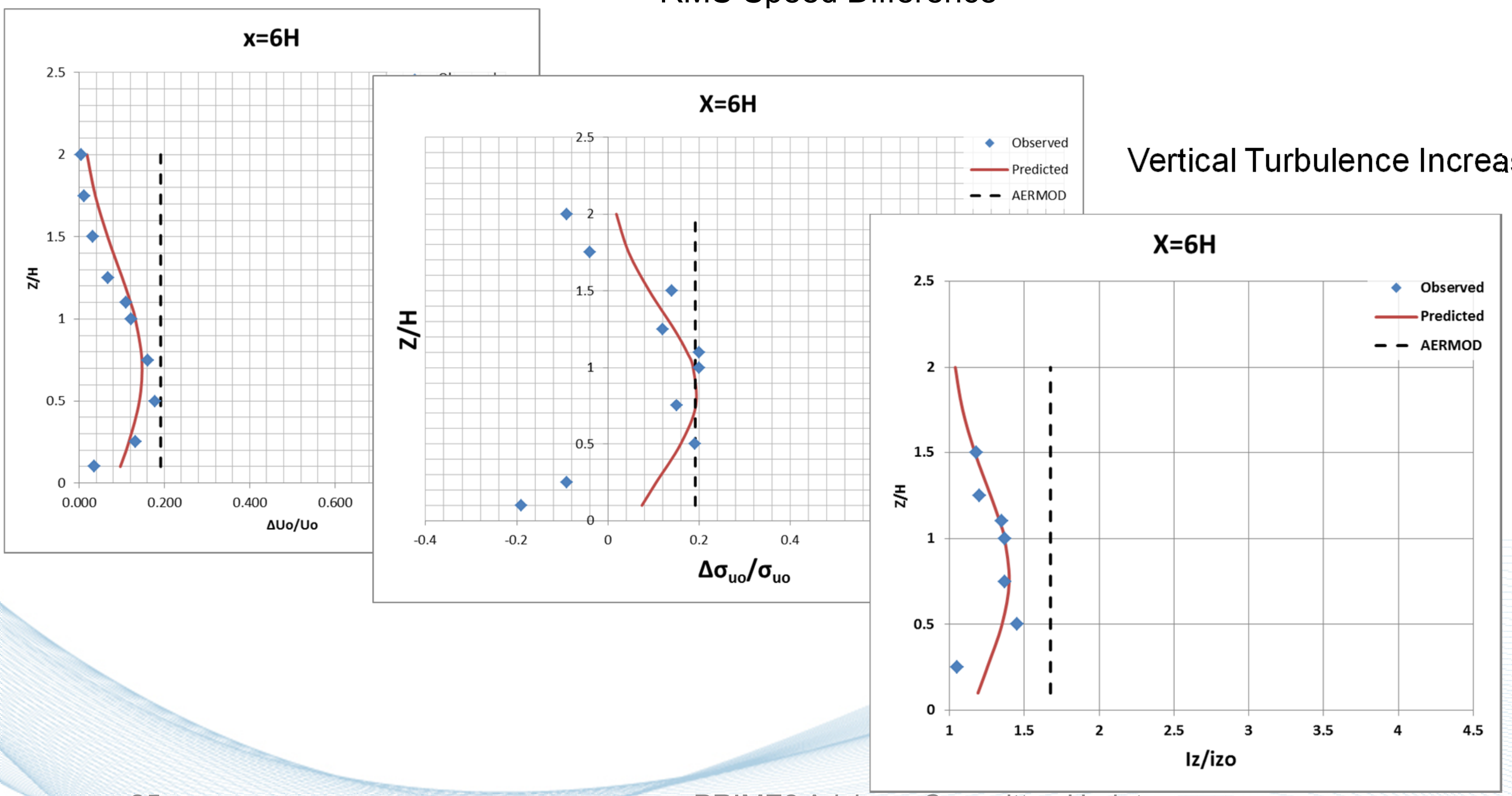
$$i_z(x,z) = i_{zo}(z)Fac(porosity)\left[\frac{1 + \frac{\Delta\sigma_{wo}}{\sigma_{wo}}(z, i_{zo}, stabity, structure\ type)\left(\frac{\xi}{H}\right)^{-\frac{2}{3}}}{1 + \Delta U_o/U_o(z, i_{zo}, stability, structure\ type)\left(\frac{\xi}{H}\right)^{-\frac{2}{3}}}\right]$$

New Equation Versus Observations Snyder Database for H:W:L = 1:1:4 Building

Mean Speed Difference

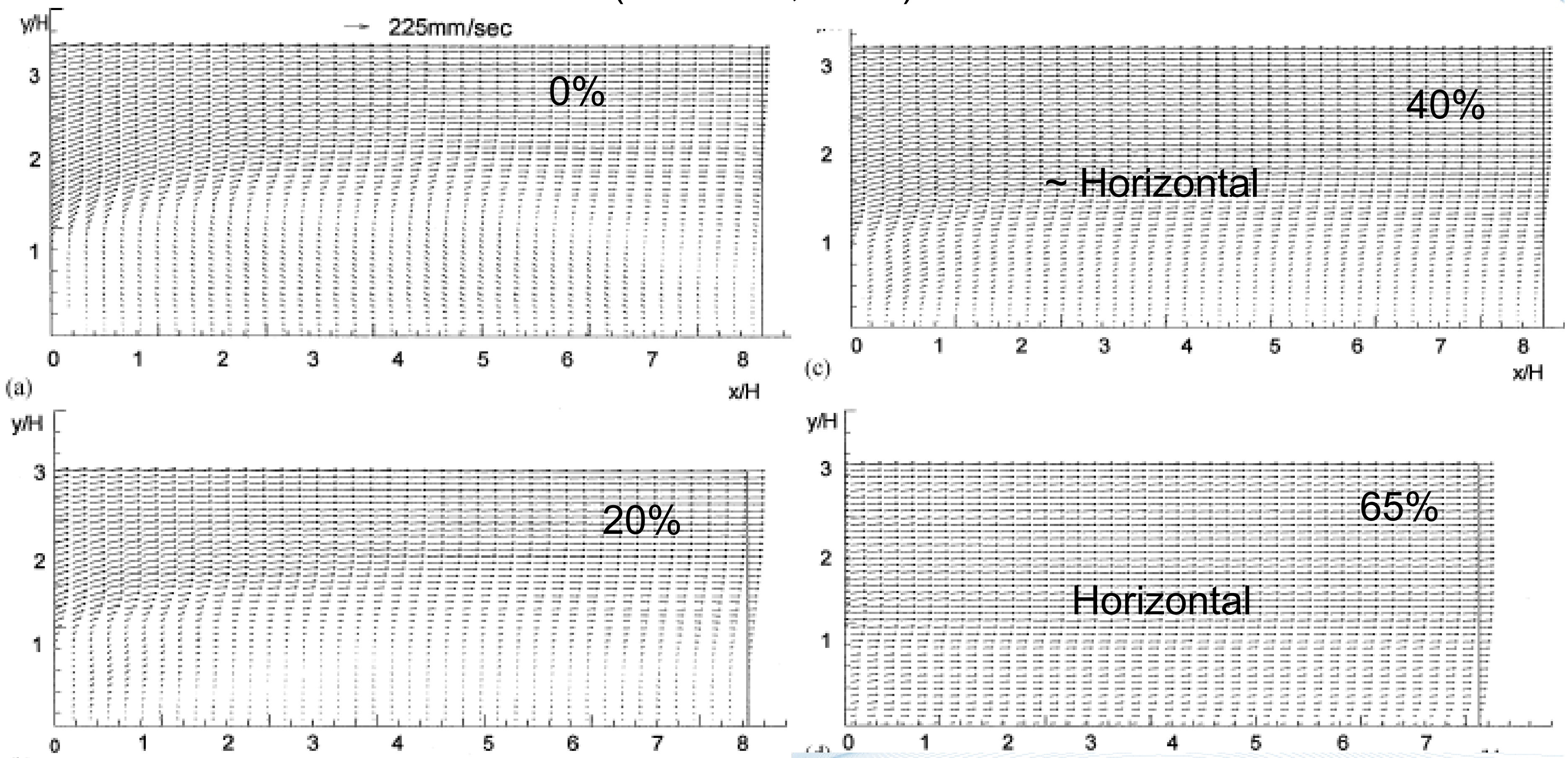
RMS Speed Difference

Vertical Turbulence Increase



Evaluation and Update PRIME Theory: Streamlines Versus Porosity

(Lee et al., 1999)



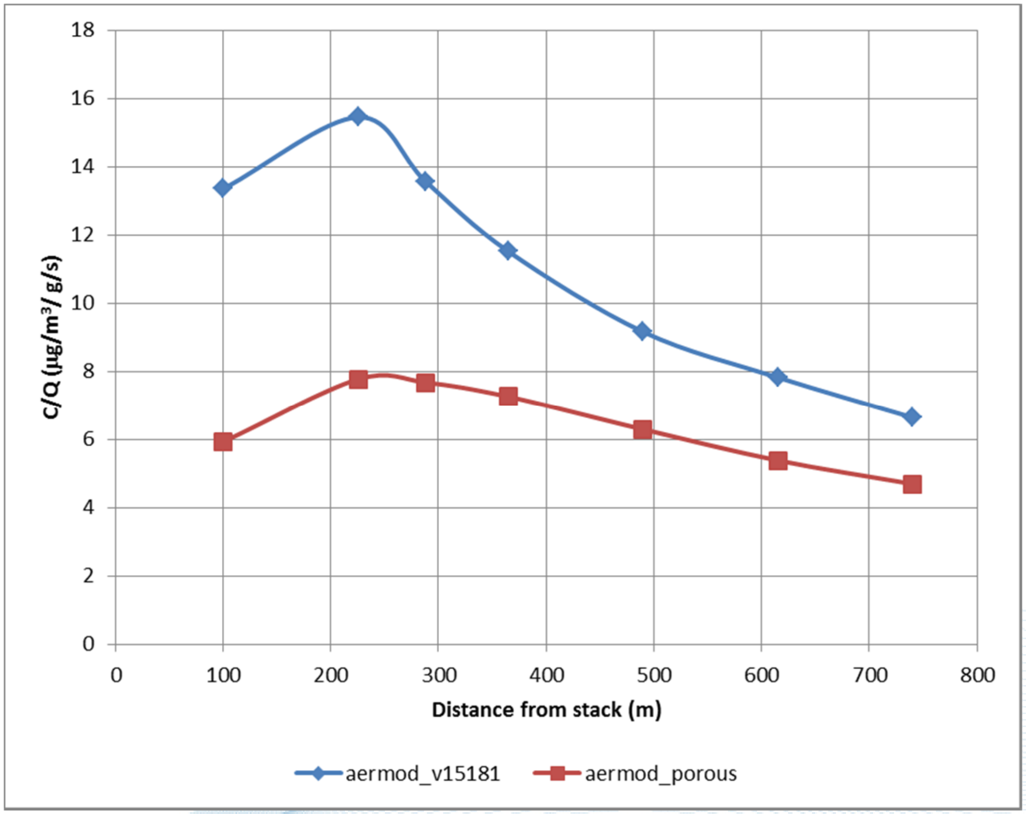
Update PRIME Formulation

- Based on results of Task 3 the PRIME subroutine will be updated
- Likely updates for solid structures
  - velocity/turbulence decay to ambient above building roof
  - Improved velocity/turbulence decay rate versus downwind distance
- Likely updates for porous structures
  - Make streamlines horizontal
  - Update the velocity deficit/turbulence enhancement constants.

PRIME2 Porous Structures Streamlines Update

Building: H= 30 m; W = 60 m; L = 30 m; X_{adj}= -30 m
H_s = 33 m; Ve = 20 m/s; UH_s = 15 m/s

- PRIME modified to make streamlines horizontal for porous structures.
- AERMOD recompiled and test case run.



Evaluation of PRIME2 Against Existing Wind Tunnel Databases

- PRIME2 will be tested against relevant CPP existing databases
- PRIME2 will be tested against selected Thompson datasets where wind tunnel and PRIME predictions agreed well and where they showed poor agreement.
  - four building geometries
  - five stack heights in range 0.5 to 4 H_b
  - various stack locations

Limited Consequence Analysis

- Two building configuration
  - H_b= 40 m, L = W = 400 m (similar to Snyder and Lawson)
  - Lattice structure from previous CPP EBD study
- Two meteorological stations: Davenport, IA and Pascagoula, MS
- Three stack heights: 1.2 H_b; 1.5 H_b; 2.5 H_b;
- Stack parameters: Q = 1 g/s; Ve = 15 m/s; d = 1 m; Ts = 400K.
- Comparisons
  - Q-Q plots of PRIME2 versus PRIME
  - Box Plots of bias versus rms difference

Phase 2 Preliminary Scope

- Correct the problems in the theory not addressed in Phase 1
  - Streamlined structures (hyperbolic cooling towers and tanks)
  - Building downwash enhancement factor variation based on approach turbulence due to different land use and land cover (e.g., grassland, urban, etc.)
- BPIP building length correction
- Test PRIME2 against appropriate field and wind tunnel databases
- Technical report that fully documents PRIME2
- Publish Phase 1 and 2 results in a peer reviewed Journal
- Collaboration with EPA to work toward implementing the improved model

Save the Date

7th A&WMA SPECIALTY CONFERENCE

Guideline on Air Quality Models: The Changes

The Air and Waste Management Association, in conjunction with the Atmospheric Modeling and Meteorology Committee (APM) of the Technical Council, is planning its 7th Specialty Conference on issues related to the Guideline on Air Quality Models (40CFR Part 51 Appendix W). The conference is planned for:

November 14-16, 2017
Sheraton Chapel Hill Hotel • Chapel Hill, North Carolina

Call for Abstracts will be announced in **January 2017**

Thank You!

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